Inter-comparison and Synergy Between the Two Long-term Global Aerosol Products Derived From AVHRR and TOMS

Myeong-Jae Jeong and Zhanqing Li
Department of Meteorology, University of Maryland, College Park, MD 20742
D. Allen Chu and Si-Chee Tsay
NASA/Goddard Space Flight Center, Greenbelt, MD 20771

Introduction

Eighteen years of satellite-based monthly aerosol products have been derived from the AVHRR and TOMS sensors. The two products differ in many regards rendering a great potential for developing an integrated product of considerable value for climate studies. Presented in this paper are some preliminary results of inter-comparison and synergy analyses.

DATA

The datasets under study include aerosol optical thickness (AOT) and Angstrom exponent derived from AVHRR under the Global Aerosol Climatology Project (GACP; http://gacp.giss.nasa.gov/; Mishchenko et al., 1999; Geogdzhayev et al., 2002) and AOT (Torres et al., 1998 and 2002) and Aerosol Index (AI) from TOMS (http://toms.gsfc.nasa.gov). AERONET(http://aeronet.gsfc.nasa.gov/) Level 2.0 data and monthly MODIS data (2000, version 3) were also used for the comparison of GACP and TOMS data.

Aerosol Climatology

Satellite aerosol estimates over the eighteen years show aerosols may be characterize in the context of climatology. In spite of high aerosol variability with space and time, distinct regional and seasonal distribution features are clearly seen (Fig. 1). Thus, they might be used in the climate studies such as the earth's radiation budget. In addition, it is anticipated that satellite-based aerosol retrieval cannot provide a high accuracy for instantaneous estimates while long-term averages could be a better estimates by compensating errors from various sources (Mishchenko et al., 1999). These long-term dataset can be further improved by rescaling through comparisons with estimates from current and future satellites designed specifically for aerosol retrieval by reducing some biases which were not removed by averaging.

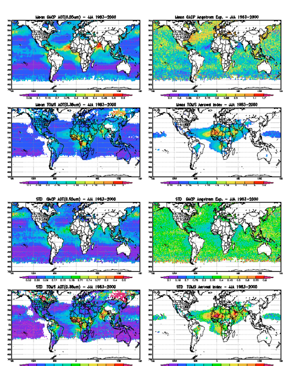


Fig. 1 Seasonal means (only JJA is presented here; upper 4 panels) and standard deviations (lower 4 panels) of GACP AOT, GACP Angstrom Exponent, TOMS AI and AOT (clockwise from the upper left; 1983-2000).

Fig. 2. Sample aerosol regions over the Ocean. [right]

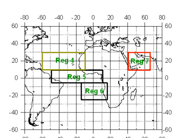
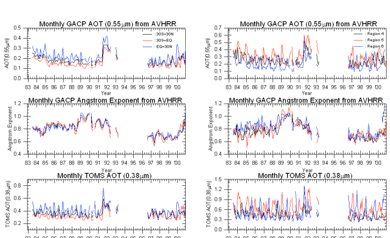


Fig. 3. Time series of co-located and coincident (monthly basis) GACP AOT, Angstrom exponent and TOMS AOT over selected regions (1983-2000). [below]



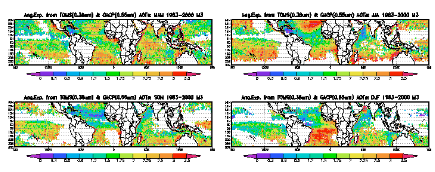
Several aerosol regions (Fig. 2) over the ocean were selected in reference to the feature shown in Fig. 1 and other researches (e.g., Hursar et al., 1997) for further analysis. Fig. 3 represents time series of monthly mean values of GACP AOT, Angstrom exponent, and TOMS AOT. As shown, seasonal variations are clear for all the variables, and decadal variations are also present. Decadal variations of AOTs are related with two major volcanic eruptions (Mt. El Chichon in 1982; Mt. Pinatubo in 1991). No visually discernable trend was found; moreover, it seems to be dangerous to dealing such a "small trend" partially due to uncertainties in sensor calibration. It has been reported that any slow linear trends of the global mean are unlike to be monitored from ISCCP datasets, which GACP products are based on, due to lack of confirmation of the long-term calibration (Brest et al., 1997; Rossow and Schiffer, 1999). The very low-frequency variability of Angstrom exponent is also suspected as an artifact in view of its sensitiveness to small residual errors of measured radiance and discordance of its direction of change with expected influences of volcanic eruptions (Geogdzhayev et al., 2002)

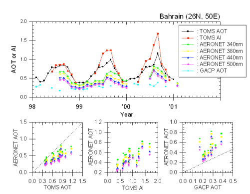
Possibility of Synergy

Aerosol retrievals from TOMS and AVHRR, which were not designed for aerosol inference, did a good job generating long-term climatology despite the limitations of instruments in addition to general difficulties in aerosol inference from space. However, no single dataset covers the entire globe and their spatial and temporal coverage differs from each other. For example, TOMS-based products can usually cover land areas but they are limited within lower latitude while AVHRR-based products have more coverage toward higher latitude (~70deg) but no coverage over land. Moreover, each dataset has it's own advantages and disadvantages. Therefore, one may hope that a synergetic product could be produced by combining the two long-term satellites observations.

At the first step, each satellite estimate was compared against AERONET measurements (Fig. 4). Because of possible large sampling biases and the representativeness problem of point location (Kinne et al., 2002), Fig.4 could not be a quantitative validation; however, at least, it can be seen that each data are correlated to each other while TOMS AOT tends to overestimate and GACP AOT underestimates in comparison with AERONET measurements at the given location. One thing notable in Fig. 4 is the discrepancy between the ground observations and satellite estimate is greater for higher aerosol load, which must be related to dust events for this region, suggesting that TOMS-based products are more sensitive to dust whereas GACP AOT looks less sensitive. This fact may be accounted by differences in retrieval algorithms of the two, possibly in association with aerosol models employed.

Next, as a diagnosis tool to examine the consistency between two datasets, Angstrom exponent (α) was calculated from TOMS and GACP AOTs. Of course, α is not an absolute tool for checking their spectral consistency because it depends on aerosol size distributions and their optical properties (Eck et al., 1999); however, α will reside around a certain range of values (normally 0.5~2; Kinne et al., 2001) within the variability of aerosol size and types. Unfortunately, according to Fig. 5 and Fig. 6, GACP and TOMS AOTs seem to be spectrally inconsistent to each other.





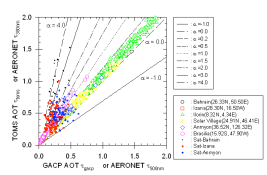


Fig. 4. A comparison of satellite-based estimates (TOMS AOT & AI and GACP AOT) with AERONET data (Bahrain, 1998-2000).[left-upper]

Fig. 5. Seasonal means of Angstrom exponent derived from TOMS and GACP AOTs . [above]

Fig. 6. Scatter plots for TOMS and GACP AOTs (380nm & 550nm, respectively) and AOTs (380nm & 500nm) measured from several AERONET sites, some of which are expected to be dominated by different types of aerosols. Lines of constant Angstrom exponent at the two wavelengths (380nm & 550nm) are also presented.[left-lower]

Comparison of GACP and MODIS AOTs

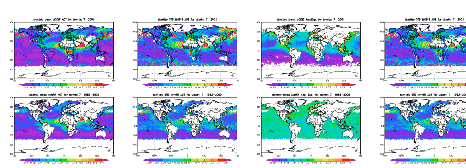


Fig. 7. Monthly means (July, 2001) of MODIS AOT and Angstrom exponent, and those for GACP grand monthly means (July averaged over 1983-2000)[1st & 3rd columns]. Standard deviations(STD) are also presented in the 2nd & 4th columns. [MODIS: upper panels; GACP: lower panels] Please note that STD for MODIS stands for the variability in a month, while that for GACP represents the inter-annual variability.

As another diagnosis method, the long-term GACP climatology was compared with MODIS data (2001). Comparison of the same individual monthly data was not made in consideration of lack of data availability and quality deterioration of AVHRR data toward the end of NOAA 14's life (Geogdzhayev, 2002). Although the periods of the two datasets are different, major features are similar to each other as shown in the Fig. 7; on the other hand, their magnitudes differ significantly from each other with different manners for different regions. Basically, a part of discrepancies should originate from difference in the averaging periods; however, other factors such as differences in aerosol models employed, sensor resolution/FOVs, wavelength selections for retrieval, cloud screening, calibration uncertainty, other instrumental/orbital factors and so on. Among these factors, the impacts of difference in aerosol models may be interesting to investigate.

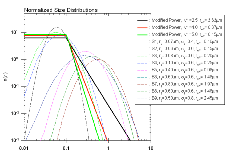


Table 1. Detailed model match-up results shown in the Fig. 8.

MODIS model ID	MP model match-up	MODIS Model ID	MP model match-up
S1	7, **8**	B5	2, 3
S2	5, 6, **7**, 8	B6	1, **2**
S3	5, **6**, 7, 8	B7	**1**, 2
S4	4, 5, 6, 7, 8	B8	2
		B9	2

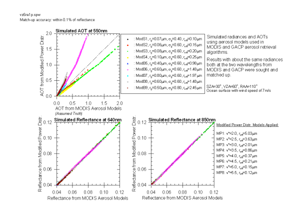


Fig. 8. Aerosol size distributions adopted by GACP (modified power distribution) and MODIS (log-normal distribution) aerosol retrieval algorithms. [upper]

Fig. 9. Simulated reflectances at 640nm & 850nm and corresponding AOT at 550nm based on aerosol models used in MODIS and GACP aerosol retrieval algorithm. Simulation results with about the same reflectances both at the two wavelengths from two different types of aerosol models were sought and matched up.[lower]

The experiment shown above (Fig. 8~9 & Table 1) is designed to estimate range of errors due to differences in aerosol models employed by the algorithms. For simplification, experiments were performed for modified power distribution with 8 different shape factor values and several single mode log-normal distributions with optical properties used by the MODIS ocean algorithm. Results show that modified power distribution-based retrieval may significantly overestimate both AOT and particle size for larger particles; on the contrary, it may underestimate AOT but with relatively good particle size estimates for smaller particles. However, the results of this experiment are contradictory to the observations shown in Fig7, especially for dust and biomass burning regions, suggesting that other factors may be dominant.

In fact, MODIS aerosol retrieval (Kaufman and Tanre, 1998) is based on the bi-modal log-normal size distribution, which is a combination of small and large modes with different weights among four small and five large mode models. In addition, the weight (or fine mode fraction) is one of variable to be inferred; thus, detailed considerations about the effects of aerosol model differences on retrieved AOT are very complicated problem in addition to local minimum solution problem in both retrieval algorithms utilizing look-up tables(LUT). However, in light of the fact that the MODIS LUT is based on the simplification suggested by Wang and Gordon (1994) that the multiple scattering radiance from two log-normal modes can be approximated by the weighted average of the radiances of each individual mode for the same optical thickness(Kaufman and Tanre, 1998), a further analysis can be possible by combining radiances from small and large modes with various fractions.

Summary and Future Work

Long-term satellite estimations based on AVHRR and TOMS showed distinct regional and seasonal distributions of aerosols in spite of high aerosol variability with space and time and many limitations to the aerosol retrieval from the measurements by non-aerosol-specific instruments. In the hope of generating a synergetic aerosol product from these long-term datasets by compensating shortcomings of each other, the possibility of combining TOMS and GACP AOTs was examined. Unfortunately, these two products seem to be spectrally inconsistent to each other; therefore, they appear to be at least inadequate to be directly-quantitatively- combined.

A comparison will be made using the same individual monthly data of MODIS(version 4) and GACP. Influence of other factors causing discrepancies among the satellite aerosol estimates and ground-based measurements will be investigated. A hybrid approach will be sought to better estimate aerosol properties, especially to identify signals from significantly absorbing aerosols by using TOMS and AVHRR-based aerosol products as well as ground-based observations.

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